

ORGANIC ANALYSIS IN MILLER RANGE 090657 AND BUCKLEY ISLAND 10933 CR2 CHONDRITES: PART 1 IN-SITU OBSERVATION OF CARBONACEOUS MATERIAL T. Cao¹, K. Nakamura-Messenger², E. L. Berger³, A. S. Burton², S. Messenger² and S. J. Clemett⁴ ¹University of California, Merced, CA, ²Astromaterials Research and Exploration Science Division, NASA Johnson Space Center, Houston, TX, ³GeoControl Systems Inc – Jacobs, NASA Johnson Space Center, Houston, TX, USA, ⁴ERC Inc – Jacobs, NASA Johnson Space Center, Houston, TX, USA. keiko.nakamura-1@nasa.gov

Introduction: Primitive carbonaceous chondrites contain a wide variety of organic material, ranging from soluble discrete molecules to insoluble unstructured kerogen-like component as well as structured nanoglobules of macromolecular carbon. The relationship between the soluble organic molecules, macromolecular organic material, and host minerals are poorly understood. Due to the differences in extractability of soluble and insoluble organic materials, the analysis methods for each differ and are often performed independently. The combination of soluble and insoluble analyses, when performed concurrently, can provide a wider understanding on spatial distribution, and elemental, structural and isotopic composition of organic material in primitive meteorites. Furthermore, they can provide broader perspective on how extraterrestrial organic materials potentially contributed to the synthesis of life's essential compounds such as amino acids, sugar acids, activated phosphates and nucleobases [1,2].

Using macroscale extraction and analysis techniques in combination with *in situ* microscale observation at NASA Johnson Space Center (JSC), we have been studying both insoluble and soluble organic material in primitive astromaterial samples. We present here the results of the analysis of carbonaceous materials in two CR2 carbonaceous chondrites using scanning electron microscopy (SEM), and transmission electron microscopy (TEM). This study is the first step for comprehensive coordinated analysis using a NanoSIMS and two-step laser mass spectrometer (μ -L²MS) at JSC. In an accompanying abstracts [3, 4] we discuss C and N isotopic imaging and soluble organic material in the samples. By performing the consortium studies, we aim to improve our understanding of the relationship between the meteorite minerals and the soluble and insoluble organic phases.

Samples and Analysis Methods: Two CR2 carbonaceous chondrites: Miller Range (MIL) 090657 and Buckley Island (BUC) 10933 were selected for this study. These CR chondrites have not been extensively characterized, but based on available data and their petrographic descriptions, they appear to have experienced minimal aqueous alteration [5-9]. To prepare samples for both SEM and TEM analyses, fine grained (50 – 100 μ m) dark fragments were carefully selected from each of the two specimen's matrices. Matrix fragments were then embedded in low-viscosity epoxy resins or pure sulfur to enable further organic analysis. Thin sections

of 70-100 nm-thickness were prepared using ultramicrotomy and deposited on TEM grids. Bright and dark-field images were obtained using a JEOL 2500SE field-emission scanning TEM at JSC. This instrument is equipped with an energy-dispersive X-ray detector (EDX) analysis system, capable of nanometer-scale compositional mapping. The samples remaining in the epoxy stubs were carbon coated and analyzed using the JEOL 7600F SEM instrument at JSC. EDX spot analyses were acquired to capture *in situ* mineral and elemental content at areas of interest.

Results: BUC 10933: The matrix fragments of BUC 10933 are dominated by fine-grained pyroxene grains. Fe, Ni-metal grains (~ 10 μ m in size) and abundant sulfide grains (~ 1 μ m in size), which are scattered throughout the pyroxene matrix. TEM analyses of ultramicrotomed thin sections from six BUC 10933 matrix fragments did not reveal any nanoglobules or other types of distinct carbonaceous matter.

MIL 090657: There are three distinct silicate lithologies in the matrix material: 1) submicron polycrystalline (Fig.1A bottom), 2) amorphous (Fig.1A top) and 3) hydrated silicates.. The dominant lithology (#1) is composed of submicron euhedral polycrystalline silicate grains. Elaborate carbonaceous material networks are found between grains. EDX analyses indicate that these silicate grains are olivine and pyroxene. The texture of surrounding carbonaceous material ranges from spongy to granular (Fig.1B). In the amorphous silicate lithology (#2), the carbonaceous material appears to be larger and smoother than the that found in lithology 1. Amorphous silicate domains range from fine grained (20nm) up to micron-size nodules with minor inclusions of nanophase Fe-sulfides and FeNi metal grains. The average composition of the amorphous silicate is richer in O and Fe than the average GEMS composition [10]. The volume ratio of carbonaceous matter to mineral grains is 1:1 in lithologies 1 and 2. In the hydrated silicate lithology (#3) is minor comparing to other two lithologies. The hydrated silicates occur in a paintbrush texture in 500 nm-sized nodules. The chemical composition and basal spacing (13-14 Å) of the hydrated silicates are consistent with smectite. In all of the lithologies, only minor nanoglobules, less than 400 nm in size, were identified (Fig.1C). The same sample characteristics were observed in both epoxy- and sulfur-embedded samples.

Discussions: The high abundance of pyroxene and the presence of Fe, Ni-metal grains in BUC 10933, as well as the absence of carbonaceous material in the matrix, suggest that this fragment of BUC 10933 is more similar to a CV chondrite than a CR chondrite; this is consistent with a previously reported data [6]. Further mineralogical investigation is required to obtain an accurate classification of BUC 10933.

The proportion of the MIL 090657 silicate lithologies (crystalline/amorphous/hydrated) observed in our TEM study is consistent with previously reported XRD data (~6 vol.% phyllosilicate and 11 vol.% amorphous) [8, 9].

The elaborate networks of granular carbonaceous materials observed throughout the polycrystalline silicate lithology in the MIL 090657 matrix have not been previously reported for any other primitive meteorite. The transition between the amorphous and polycrystalline silicate lithologies indicate that the sample has undergone a limited thermal annealing event, which was mild enough that decomposition of organic matter did not occur. According to annealing experiments done on a CR3 meteorite amorphous silicate matrix [11], the polycrystalline silicates formed from amorphous silicates that experienced a short duration annealing event (700 °C, two hours). The granular texture of carbonaceous material in the polycrystalline silicate lithology might be related to the same heating event [12]. Alternatively, abundant ¹⁵N hotspots observed in the companion abstract [3] suggests that these may be relicts of pre-accretionary nebular or interstellar environments.

Conclusions: BUC 10933 more closely resembles CV chondrites than CR chondrites. MIL 090657 contains extensive networks of carbonaceous materials that differ in morphology relative to what has previously been observed for CR3 chondrites. This implies that MIL 090657 experienced localized minor aqueous and brief thermal alteration. The differences in carbonaceous morphology suggests that the sample experienced different levels of alteration. In future work, we will use *ultra* L²MS at JSC to investigate the nature and in-situ distribution of these organic phases.

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Figure 1: STEM Bright Field Images of MIL 090657 matrix showing multiple carbonaceous material morphologies: **A:** the dominant amorphous silicate lithology and polycrystalline silicate lithology. The dotted line indicates the lithology boundary. The material with lighter contrast is carbonaceous. **B:** a magnified view of the network of carbonaceous material found in the granular polycrystalline lithology. **C:** a hollow nanoglobule (right) and smooth carbonaceous matter (left) from the amorphous silicate lithology.

